

Eucalyptus and 1,8-Cineole in Poultry Nutrition: A Review of Their Potential as Phytogetic Feed Additives

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ABSTRACT

The increasing concern over the routine use of antibiotic growth promoters in poultry production has stimulated interest in phytogetic feed additives as natural alternatives. Among these, *Eucalyptus* and its essential oil have received attention because of their bioactive constituents, particularly 1,8-cineole (eucalyptol), and their potential antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory properties. This review examines the potential application of *Eucalyptus* essential oil and its major bioactive components in poultry nutrition, with particular emphasis on growth performance, feed conversion efficiency, nutrient digestibility, intestinal health and microbiota, immune responses, antioxidant status, and resistance to environmental and disease-related challenges. Available studies indicate that dietary *Eucalyptus* preparations may improve selected productive and physiological responses in poultry; however, outcomes vary according to the plant species, chemical composition, inclusion level, form of supplementation, bird age, diet, and experimental conditions. Particular attention is given to 1,8-cineole, including its antioxidant and antimicrobial activities and the potential benefits of microencapsulation for improving its stability and biological effectiveness. The review also considers the possible limitations of *Eucalyptus*-derived products, including tannins and inconsistent responses at different supplementation levels. Overall, *Eucalyptus* essential oil and 1,8-cineole show potential as phytogetic feed additives in poultry production, but further well-controlled studies are required to establish optimal inclusion levels, safety, efficacy, and practical applications under commercial production conditions.



KEYWORDS: Eucalyptus; 1,8-cineole; essential oil; phytogetic feed additives; poultry nutrition; broiler chickens; gut health

1. INTRODUCTION

Poultry production continues to face the challenge of maintaining high productive efficiency while protecting intestinal health, animal welfare, and food safety. Antibiotics have historically been used in animal production to improve health and growth performance; however, concerns regarding antimicrobial resistance and antibiotic residues have accelerated efforts to identify effective alternatives to antibiotic growth promoters (Wang et al., 2024).

Among the proposed alternatives, phytogetic feed additives (PFAs), also referred to as phytoiotics or botanical feed additives, have attracted considerable interest in poultry nutrition. PFAs encompass herbs, spices, essential oils, plant extracts, and their bioactive constituents, including terpenoids, polyphenols, and flavonoids. Their potential antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory activities may contribute to improved animal health and productive performance (Biswas et al., 2024; Wang et al., 2024).

The gastrointestinal tract is particularly important in poultry because efficient digestion and nutrient absorption depend on maintaining intestinal integrity and a balanced microbial ecosystem. Disturbances in intestinal microbiota and barrier function can contribute to inflammation, impaired nutrient utilization, and reduced productive performance (Ducatelle et al., 2023). Accordingly, nutritional interventions capable of supporting intestinal function and microbial balance have become an important component of antibiotic-reduction strategies in poultry production.

Essential oils constitute an important group of phytogetic additives because they contain biologically active volatile compounds capable of influencing microbial populations, oxidative processes, inflammatory responses, and digestive function. Recent evidence indicates that essential oils may contribute to poultry health and performance, although their practical application can be limited by volatility, poor water solubility, variable intestinal absorption, and sensitivity to environmental conditions. Encapsulation and nanoformulation technologies are consequently receiving increasing attention as strategies to enhance their stability and bioavailability (Movahedi et al., 2024).

Among essential-oil-producing plants, *Eucalyptus* species are of particular interest because their leaves contain substantial quantities of volatile terpenoids. 1,8-Cineole (eucalyptol) is frequently one of the predominant constituents of *Eucalyptus* essential oil and has been associated with antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory activities. Studies in poultry have investigated *Eucalyptus* in the form of leaf powder, essential oil, and isolated or formulated bioactive constituents, with reported effects on growth performance, nutrient utilization, intestinal microbiota, antioxidant status, and immune responses (Farhadi et al., 2017; Mohebodini et al., 2021). However, phytogetic responses are not universally consistent and can be influenced by botanical source, chemical composition, processing and extraction procedures, supplementation level, diet, bird age, and environmental conditions (Wang et al., 2024).

Therefore, this review critically examines the available evidence concerning *Eucalyptus* and its principal bioactive constituent, 1,8-cineole, as phytogetic feed additives in poultry nutrition. Particular emphasis is placed on their phytochemical composition, extraction and delivery systems, mechanisms of action, growth performance and feed efficiency, nutrient digestibility and gut health, antioxidant and immune responses, and their potential roles in alleviating environmental and disease-related challenges. In addition, inconsistent findings, potential adverse effects, practical limitations, and future research priorities are considered to provide a balanced assessment of their application in modern poultry production.

2. Phytogetic Feed Additives and Essential Oils in Poultry Nutrition

Phytogetic feed additives (PFAs) comprise a diverse group of plant-derived products, including herbs, spices, plant extracts, oleoresins, and essential oils, that are incorporated into animal diets to support health and productive performance. Their biological activities are primarily associated with bioactive constituents such as polyphenols, flavonoids, terpenoids, alkaloids, and other secondary metabolites. Increasing restrictions on antibiotic growth promoters and concerns regarding antimicrobial resistance have stimulated considerable interest in PFAs as potential natural alternatives in poultry production (Wang et al., 2024; Biswas et al., 2024). Recent evidence indicates that phytogetic compounds can exert antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory effects, although their efficacy depends strongly on botanical origin, chemical composition, processing, dosage, and dietary and physiological conditions.

Among PFAs, essential oils are particularly promising because they are concentrated mixtures of volatile plant compounds, predominantly terpenes, terpenoids, and other aromatic constituents. Essential oils obtained from plants such as oregano, thyme, cinnamon, rosemary, peppermint, and *Eucalyptus* have been extensively investigated for their potential application in poultry nutrition. Their antimicrobial activity is associated partly with interactions between hydrophobic constituents and microbial cell membranes, whereas antioxidant and anti-inflammatory activities may contribute to maintaining intestinal integrity and physiological homeostasis. These multiple biological activities may consequently influence nutrient utilization, intestinal microbial populations, immune responses, and productive performance (Biswas et al., 2024; Oni & Oke, 2025).

The gastrointestinal tract represents an important target for phytogetic supplementation. PFAs may influence digestive enzyme activity, intestinal morphology, barrier integrity, microbial balance, and immune function. Modulation of these processes can potentially enhance nutrient digestion and absorption while suppressing undesirable intestinal microorganisms. Recent reviews indicate that phytogetic compounds can promote beneficial microbial populations and intestinal integrity, although responses remain dependent on the type and concentration of the bioactive compounds employed (Oni & Oke, 2025).

Despite their potential benefits, the practical use of essential oils in poultry feeds presents several challenges. Their high volatility, low water solubility, susceptibility to degradation, variable composition, and sometimes limited intestinal absorption may reduce their effectiveness. Furthermore, excessive inclusion of certain phytogetic compounds can adversely affect feed palatability or physiological responses, demonstrating that natural origin does not necessarily guarantee efficacy or safety at all concentrations (Wang et al., 2024).

Recent technological approaches, particularly encapsulation and nanoformulation, have therefore been investigated to protect essential oils from degradation and improve their stability, controlled release, intestinal delivery, and bioavailability. Such delivery systems may allow lower and more consistent effective doses of essential oils in poultry diets. Nevertheless, additional research is required to establish standardized formulations, optimal supplementation levels, long-term safety, and economic feasibility under commercial poultry-production conditions (Movahedi et al., 2024). Within this broader group of phytogetic additives, *Eucalyptus* essential oil is of particular interest because of its characteristic terpenoid composition and high abundance of 1,8-cineole (eucalyptol). Its chemical composition and biological properties provide the basis for its potential application in poultry nutrition and are discussed in the following sections.

3. Eucalyptus Essential Oil: Sources and Chemical Composition

Eucalyptus is a diverse genus of the family Myrtaceae comprising numerous aromatic species whose leaves are important sources of essential oils. The composition and yield of *Eucalyptus* essential oil (EEO) vary considerably among species and are also influenced by geographical origin, climatic conditions, plant developmental stage, harvesting conditions, plant part, and extraction method. Consequently, considerable compositional variation can occur even within essential oils obtained from the same *Eucalyptus* species (Yip et al., 2024).

The volatile fraction of EEO consists predominantly of monoterpenes and oxygenated monoterpenes, together with smaller quantities of sesquiterpenes and other volatile compounds. Among these constituents, 1,8-cineole (eucalyptol) is frequently the predominant compound, particularly in *Eucalyptus globulus*. Other commonly detected constituents include α -pinene, β -pinene, limonene, *p*-cymene, γ -terpinene, α -terpineol, aromadendrene, and related terpenoids (Ghaffar et al., 2015; Sebei et al., 2015; Yip et al., 2024).

Importantly, the concentration of 1,8-cineole should not be presented as a fixed percentage. Considerable variation has been reported among *Eucalyptus* oils. For example, one chemical characterization of *E. globulus* essential oil identified 1,8-cineole as the major constituent at 63.1%, followed by *p*-cymene (7.7%), α -pinene (7.3%), and limonene (6.9%) (Čmíková et al., 2023). More recent work has similarly demonstrated substantial variation, with an *E. globulus* essential oil analysed in 2024 containing 86.1% 1,8-cineole (Kačániová et al., 2024). This variability is particularly relevant to animal nutrition because differences in phytochemical composition may contribute to inconsistent biological responses among supplementation studies.

Among the volatile constituents, 1,8-cineole is of particular interest because it has been associated with several biological activities relevant to poultry nutrition, including antimicrobial, antioxidant and anti-inflammatory effects. Nevertheless, the biological activity of EEO should not be attributed exclusively to 1,8-cineole because interactions among multiple constituents may contribute to the overall activity of the oil (Yip et al., 2024). Therefore, chemical characterization of the EEO used in feeding trials is important when comparing its efficacy across poultry studies.

Recent poultry research reinforces this point. In a broiler study examining *E. globulus* essential oil under cold-induced physiological stress, GC-based characterization showed 67.85% 1,8-cineole, together with α -pinene (12.69%), α -terpineol (5.37%), α -phellandrene (4.15%), and *p*-cymene (2.94%). Such findings demonstrate why the botanical species, chemical profile, and concentration of major bioactive constituents should be reported when evaluating EEO as a phytogetic feed additive (Mohebodini et al., 2025).

4. Extraction of Eucalyptus Essential Oil

The extraction technique is a major determinant of the yield, chemical composition, purity, and biological properties of Eucalyptus essential oil (EEO). Conventional methods include hydrodistillation, steam distillation, and solvent extraction, whereas more advanced approaches such as microwave-assisted extraction, ultrasound-assisted extraction, and supercritical fluid extraction (SFE) have increasingly been investigated. Differences in temperature, extraction time, pressure, solvent characteristics, and plant material can substantially alter both extraction efficiency and the relative abundance of individual phytochemicals (Zhao & Zhang, 2014; Yip et al., 2024).

4.1 Hydrodistillation and Steam Distillation

Hydrodistillation remains one of the most widely used methods for recovering essential oils from Eucalyptus leaves because of its operational simplicity and avoidance of organic solvent residues. During hydrodistillation, plant material is exposed to boiling water or steam, allowing volatile constituents to vaporize and subsequently condense for oil recovery. However, prolonged exposure to elevated temperature and water can promote hydrolysis, oxidation, or degradation of thermolabile constituents, potentially altering the chemical profile of the recovered oil.

Importantly, hydrodistillation can produce oils rich in 1,8-cineole, although its concentration depends strongly on the Eucalyptus species and processing conditions. Comparative extraction studies have demonstrated that the chemical profile obtained through hydrodistillation can differ substantially from extracts produced using supercritical CO₂ or solvent-based techniques (da Cruz Francisco et al., 2001; Zhao & Zhang, 2014).

4.2 Solvent-Assisted Extraction

Organic solvents can recover a broader range of compounds than hydrodistillation because extraction is not restricted to highly volatile constituents. Soxhlet and conventional solid–liquid extraction have therefore been used to recover Eucalyptus phytochemicals using solvents of different polarities. Nevertheless, solvent selection strongly influences extraction yield and chemical composition, while solvent removal, potential residues, environmental impact, and additional processing requirements can limit the suitability of conventional solvent extraction for feed and food applications (Zhao & Zhang, 2014).

4.3 Supercritical CO₂ Extraction

Supercritical CO₂ extraction represents an attractive alternative because carbon dioxide above its critical temperature and pressure possesses useful solvent properties while enabling extraction at comparatively moderate temperatures. CO₂ is readily separated from the recovered extract following depressurization, thereby reducing concerns associated with residual conventional organic solvents. Pressure, temperature, extraction time and the use of co-solvents can be manipulated to modify extraction yield and selectivity (Zhao & Zhang, 2014; Dashtian et al., 2024).

The extraction technique can markedly influence the phytochemical profile. For example, comparative work with *Eucalyptus camaldulensis* demonstrated that hydrodistillation produced an oil containing approximately 43% 1,8-cineole, whereas supercritical CO₂ extraction changed the relative abundance of several volatile and less-volatile constituents (da Cruz Francisco et al., 2001). Similarly, work with *Eucalyptus cinerea* reported a higher essential-oil yield from hydrodistillation than supercritical CO₂ extraction, but the latter recovered a broader range of constituents (Mann et al., 2011).

Recent developments in SFE emphasize improved selectivity, process integration, and optimization of pressure, temperature and extraction configuration. Nevertheless, high-pressure equipment and associated capital and operating costs remain important considerations when assessing its commercial feasibility (Dashtian et al., 2024).

4.4 Emerging and Green Extraction Approaches

Microwave- and ultrasound-assisted techniques have also been investigated as strategies to reduce extraction time and energy consumption while improving the recovery of plant bioactive compounds. Microwave-assisted hydrodistillation, for example, has produced *Eucalyptus* essential oils in considerably shorter extraction times than conventional hydrodistillation in comparative studies. However, differences in extraction technologies can produce oils with distinct chemical profiles and consequently different biological activities.

Therefore, the extraction procedure should be considered an important source of variability when comparing studies investigating EEO as a poultry feed additive. Future feeding trials should ideally report the *Eucalyptus* species, plant material, extraction procedure, essential-oil yield, and GC–MS chemical profile, particularly the concentration of 1,8-cineole and other major constituents. This would substantially improve reproducibility and enable more meaningful comparison of dose–response relationships among poultry studies.

5. Effects of *Eucalyptus* on Growth Performance and Nutrient Digestibility

The effects of *Eucalyptus*-derived feed additives on poultry performance have been investigated using different preparations, including leaf powder, essential oil, and essential-oil blends. The current manuscript already acknowledges that responses to phytogenic supplementation are inconsistent and may depend on the composition and concentration of the additive. This is important, and I would retain that balanced approach rather than presenting *Eucalyptus* as consistently growth-promoting.

Dietary supplementation with *Eucalyptus globulus* has shown potential to influence body-weight gain, feed intake, and feed conversion efficiency in broiler chickens. Farhadi et al. (2017) evaluated *E. globulus* leaf powder and essential oil and reported improvements in selected growth and immune-response parameters, indicating that both the form and supplementation level may influence the response. Similarly, Mashayekhi et al. (2018) compared *Eucalyptus* leaf powder with probiotic and antibiotic treatments in broilers and observed treatment-dependent effects on productive performance. These findings suggest that *Eucalyptus* may have potential as a phytogenic feed additive, although the magnitude and consistency of the response cannot be generalized across feeding conditions.

More specifically, Mohebodini et al. (2021) investigated graded levels of *E. globulus* essential oil in broiler chickens and demonstrated that dietary EEO influenced growth performance together with intestinal microbial populations, immune responses, and blood-related indices. Importantly, the responses differed according to supplementation level, supporting the existence of a dose-dependent effect rather than a simple linear improvement with increasing EEO inclusion. This study is particularly valuable because it evaluates *Eucalyptus* essential oil directly in broilers and should therefore remain one of the core experimental references in this review.

The potential effects of EEO on productive performance may be associated with its influence on gastrointestinal function. Essential-oil constituents can interact with intestinal microorganisms and may affect digestive processes, intestinal morphology, and nutrient utilization. The current manuscript also discusses improvements in villus characteristics and nutrient digestibility following phytogenic supplementation. However, evidence obtained from oregano, thyme, peppermint, or mixed phytogenic preparations should not be presented as direct evidence for *Eucalyptus*. Such studies are useful for explaining possible mechanisms, but conclusions concerning the efficacy of EEO should primarily be based on *Eucalyptus*-specific poultry studies.

A study by Hesabi Nameghi et al. (2019), for example, evaluated a blend containing thyme, peppermint, and *Eucalyptus* essential oils in broilers and reported effects on growth performance, immune responses, and intestinal morphology. Because several essential oils were administered simultaneously, the observed responses cannot be attributed specifically to *Eucalyptus*. Nevertheless, the study provides supporting evidence that essential-oil combinations containing EEO may influence intestinal and productive responses in broiler chickens.

Variability among studies may arise from differences in *Eucalyptus* species, essential-oil composition, concentration of 1,8-cineole and other terpenoids, supplementation level, duration of feeding, basal diet, bird genotype and age, environmental conditions, and health status. The physical form of supplementation is another important consideration because leaf powder contains non-volatile phytochemicals and structural components that are absent or present at substantially different concentrations in distilled essential oil. Consequently, *Eucalyptus* leaf powder and EEO should not be considered biologically equivalent feed additives.

6. Effects on Gut Health, Intestinal Microbiota, and Immune Function

The gastrointestinal tract plays a central role in poultry health and productivity because efficient nutrient utilization depends on intestinal integrity, appropriate immune regulation, and a relatively stable microbial ecosystem. Phytogenic feed additives, including *Eucalyptus* essential oil (EEO), may influence these processes through the combined antimicrobial, antioxidant, and anti-inflammatory activities of their bioactive constituents. Nevertheless, evidence specific to *Eucalyptus* remains more limited than that available for phytogenic additives collectively, and therefore conclusions should be based primarily on direct poultry studies.

One of the more comprehensive investigations was conducted by Mohebodini et al. (2021), who evaluated dietary *Eucalyptus globulus* essential oil at 0, 250, 500, 750, and 1,000 mg/kg in broiler chickens. In addition to improvements in selected productive parameters and nutrient digestibility, EEO supplementation partially modified the cecal microbial population. The authors reported reductions in *Escherichia coli* and increases in *Lactobacillus* populations at particular supplementation levels, indicating that EEO may contribute to a more favourable intestinal microbial environment. However, these responses were dose dependent and were not uniform across all microbial measurements.

The antimicrobial potential of EEO is commonly associated with its volatile terpenoids, particularly 1,8-cineole, although the biological effects of the complete oil cannot necessarily be attributed to this compound alone. Hydrophobic essential-oil constituents may interact with microbial cell membranes and alter membrane permeability and cellular function. Such effects provide a plausible mechanism by which EEO could suppress selected intestinal microorganisms. However, direct evidence of these mechanisms within the chicken gastrointestinal tract remains relatively limited, and extrapolation from *in vitro* antimicrobial studies should therefore be made cautiously.

More direct mechanistic evidence is available for 1,8-cineole. Jiang et al. (2021) investigated microencapsulated 1,8-cineole in broiler chickens exposed to heat stress. Dietary supplementation with 1% or 3% 1,8-cineole microcapsules helped preserve ileal morphology and modified the intestinal microbial community under heat-stress conditions. The treatment increased the relative abundance of *Lactobacillus* while reducing *Salmonella* in the upper ileum in the principal heat-stress comparison. The study also demonstrated *in vitro* inhibitory activity of 1,8-cineole against *Salmonella*.

Importantly, the same study connected changes in the intestinal microbiota with modulation of inflammatory responses. Microencapsulated 1,8-cineole reduced heat-stress-associated intestinal inflammation and affected the expression of inflammatory mediators, including NF- κ B, TNF- α , IL-1 β , and IL-6. These findings suggest that the beneficial effects of 1,8-cineole under physiological stress may involve interactions among microbial modulation, intestinal integrity, and inflammatory signalling rather than a simple antimicrobial effect alone (Jiang et al., 2021).

Immune-modulating effects have also been reported with *Eucalyptus* preparations. Farhadi et al. (2017) evaluated *E. globulus* leaf powder at 1,000 and 3,000 mg/kg and EEO at 250 and 500 mg/kg in broilers. Birds receiving *Eucalyptus* leaf powder or essential oil showed an enhanced primary antibody response to sheep red blood cells compared with the control group, whereas the secondary antibody response was not significantly affected. Notably, leaf powder reduced growth performance during part of the experimental period, demonstrating that an improvement in an immune parameter does not necessarily correspond to improved productive performance.

This distinction is particularly important for interpreting the literature. *Eucalyptus* leaf powder and EEO contain different profiles and concentrations of volatile and non-volatile compounds and therefore should not be treated as interchangeable interventions. Similarly, studies using mixtures of *Eucalyptus* with other essential oils, probiotics, or phytogenic ingredients cannot establish that an observed immunological or intestinal response is caused specifically by *Eucalyptus*.

7. Antioxidant Status and Responses to Oxidative Stress

Oxidative stress is an important physiological challenge in poultry production and can arise from rapid growth, environmental stressors, disease, and nutritional imbalance. Excessive production of reactive oxygen species can overwhelm endogenous antioxidant defence systems, resulting in lipid peroxidation, cellular damage, and impaired physiological function. Phytogenic feed additives containing antioxidant bioactive compounds have therefore attracted interest as nutritional strategies for improving oxidative stability in poultry (Wang et al., 2024; Biswas et al., 2024).

Eucalyptus essential oil (EEO) contains several terpenoid compounds with potential antioxidant activity, particularly 1,8-cineole, although the biological activity of the whole oil may also involve interactions among other volatile constituents. Evidence from broiler chickens indicates that dietary EEO can influence endogenous antioxidant defence. Mohebodini et al. (2021) reported that supplementation with *Eucalyptus globulus* essential oil increased serum superoxide dismutase

activity and decreased malondialdehyde concentration, indicating enhanced antioxidant defence and reduced lipid peroxidation. The same study also demonstrated alterations in thigh-muscle fatty acid composition, including increased polyunsaturated fatty acids and decreased saturated fatty acids, suggesting that EEO may influence both systemic antioxidant status and lipid metabolism.

The antioxidant and physiological effects of EEO may become particularly relevant when poultry are exposed to environmental stress. Heat stress can increase oxidative pressure and disrupt physiological homeostasis, ultimately compromising health and productive performance. Petrolli et al. (2019) investigated eucalyptus oil supplementation in broilers exposed to heat stress and reported changes in productive performance, hematological variables, leukocyte responses, and respiratory microbiota. Although these findings suggest that eucalyptus oil may contribute to physiological adaptation during heat exposure, the study does not establish that all observed responses resulted directly from antioxidant mechanisms. Therefore, its findings should be interpreted as evidence of broader stress-modulating effects rather than exclusively antioxidant activity.

More recent evidence has strengthened the association between EEO supplementation and antioxidant defence under environmental stress. Mohebodini et al. (2025) investigated *E. globulus* essential oil in broilers subjected to cold-induced ascites and reported that cold stress reduced superoxide dismutase and glutathione peroxidase activities while increasing malondialdehyde concentrations in plasma and heart tissue. Dietary EEO supplementation enhanced antioxidant enzyme activities and reduced malondialdehyde concentrations, indicating attenuation of oxidative damage. EEO also increased plasma nitric oxide concentration and improved several hematological and blood-gas variables affected by cold stress. However, supplementation did not completely restore all physiological responses to the levels observed in thermoneutral birds, suggesting a mitigating rather than completely protective effect (Mohebodini et al., 2025).

Evidence specifically concerning 1,8-cineole further supports its potential role in oxidative-stress regulation. Al-Musawi et al. (2020) investigated the effects of 1,8-cineole in laying hens exposed to polychlorinated biphenyl-induced toxicity and reported improvements in antioxidant-related responses. This study provides useful evidence for the biological activity of 1,8-cineole in poultry; however, because the experimental model involved chemically induced toxicity rather than conventional production stress, its findings should not be directly extrapolated to normal commercial feeding conditions.

Similarly, Jiang et al. (2021) demonstrated that microencapsulated 1,8-cineole alleviated several adverse responses associated with heat stress in broiler chickens. In addition to its effects on intestinal microbiota and inflammatory signalling discussed previously, 1,8-cineole supplementation contributed to improved physiological resilience under heat-stress conditions. These findings indicate that the potential benefits of 1,8-cineole may involve interconnected antioxidant, anti-inflammatory, and intestinal mechanisms rather than a single pathway (Jiang et al., 2021).

Importantly, the antioxidant activity of EEO should not be attributed exclusively to 1,8-cineole. The oil contains a complex mixture of terpenoids whose concentrations vary according to *Eucalyptus* species, geographical origin, harvesting conditions, and extraction procedure (Yip et al., 2024). Consequently, differences in essential-oil composition may partly explain the variability in antioxidant and physiological responses reported among poultry studies.

8. Effects of Eucalyptus under Environmental Stress and Disease Challenges

Environmental and infectious challenges can substantially impair poultry health and productivity through alterations in oxidative balance, immune function, intestinal integrity, and feed utilization. The antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory properties attributed to *Eucalyptus* essential oil (EEO) and its bioactive constituents have therefore stimulated interest in their potential application under stress and disease-challenge conditions. However, the strength of evidence differs considerably among heat stress, cold stress, viral infection, and parasitic disease.

8.1 Heat and Cold Stress

Heat stress is an important constraint in poultry production because prolonged exposure to elevated environmental temperatures can negatively affect feed intake, growth, physiological homeostasis, immune responses, and intestinal health. Petrolli et al. (2019) investigated eucalyptus oil administered through drinking water and spray application to broilers maintained under heat-stress conditions. Eucalyptus oil influenced selected hematological and leukocyte parameters and respiratory microbiota and could be administered without impairing bird development. However, the findings did not demonstrate a consistent improvement in all productive variables. Thus, this study supports the potential physiological application of eucalyptus oil during heat stress but does not justify describing it as a complete solution for heat-stress-associated production losses.

The potential of 1,8-cineole under heat stress has also been demonstrated by Jiang et al. (2021). As discussed previously, microencapsulated 1,8-cineole helped alleviate heat-stress-associated intestinal inflammation, alterations in intestinal morphology, and microbial imbalance in broilers. These findings are particularly relevant because they indicate that the stress-mitigating action of 1,8-cineole may involve interactions among intestinal microbiota, inflammatory signalling, and maintenance of intestinal integrity rather than solely improvements in growth performance.

Cold stress represents another environmental challenge, particularly because sustained exposure to low temperature can increase metabolic and cardiovascular demands and predispose broilers to pulmonary hypertension and ascites. More recently, Mohebodini et al. (2025) provided stronger experimental evidence that dietary *E. globulus* essential oil can attenuate cold-induced physiological disturbances in broilers. As discussed in Section 7, EEO improved antioxidant enzyme activities, reduced lipid peroxidation, and partially improved hematological and blood-gas disturbances associated with cold-induced ascites. Nevertheless, the responses were not completely restored to those of thermoneutral birds, reinforcing the interpretation of EEO as a potentially supportive stress-mitigation strategy rather than complete protection against cold stress.

8.2 Newcastle Disease and Respiratory Challenges

The potential immunomodulatory effects of *Eucalyptus* have also been investigated under infectious challenge. Barbour et al. (2013) evaluated a combination of eucalyptus and peppermint essential oils in broilers challenged with velogenic Newcastle disease virus (vNDV). Among challenged birds, vaccinated chickens receiving the essential-oil treatment exhibited better survival, body weight, feed conversion, and serological responses than selected challenged comparison groups. The authors concluded that the essential-oil preparation could potentiate the response to Newcastle disease vaccination.

These results should, however, be interpreted carefully. The preparation contained both eucalyptus and peppermint essential oils, meaning that the observed effects cannot be attributed exclusively to *Eucalyptus*. Moreover, phytogenic supplementation should not be presented as a substitute for vaccination or established disease-control measures. Instead, the available evidence suggests a possible adjunct immunomodulatory role that requires confirmation using chemically characterized EEO alone and contemporary disease-challenge models.

8.3 Coccidiosis

The original manuscript contains an extensive general discussion of poultry coccidiosis, including bird age, genetics, concurrent infection, and *Artemisia annua*. Much of this material is not directly related to *Eucalyptus* and should be removed. However, the coccidiosis subsection itself should now be retained and substantially updated, because recent studies provide direct evidence for eucalyptus-containing preparations against *Eimeria tenella*.

Geng et al. (2024) investigated a botanical formulation containing eucalyptus oil, apigenin, and eugenol essential oil in *E. tenella*-challenged broilers. The formulation showed moderate anticoccidial activity and reduced several adverse consequences of infection while demonstrating a favourable safety profile at the tested concentrations. Because the intervention contained three bioactive components, however, its effects cannot be assigned specifically to eucalyptus oil.

More importantly, Huang et al. (2025) subsequently evaluated eucalyptus oil itself in an *E. tenella* infection model. Dietary supplementation at 20 mg/kg reduced cecal damage, oocyst shedding and mortality and improved body-weight recovery, producing an anticoccidial index of approximately 160, which the authors interpreted as moderate anticoccidial activity. Eucalyptus oil also attenuated infection-associated oxidative imbalance and inflammatory responses and influenced molecular markers associated with *Eimeria* invasion and apoptosis. In addition, inhibition of *Clostridium perfringens* proliferation was observed both *in vivo* and *in vitro*.

9. 1,8-Cineole: Biological Functions and Potential in Poultry Nutrition

9.1 Occurrence and Biological Significance

1,8-Cineole, commonly known as eucalyptol, is an oxygenated monoterpene and one of the principal volatile constituents of many *Eucalyptus* essential oils. Although particularly associated with *Eucalyptus*, 1,8-cineole also occurs in several other aromatic plants, including rosemary, sage, cardamom, and bay species. Its concentration in *Eucalyptus* essential oil varies considerably according to species, genotype, geographical origin, environmental conditions, plant maturity, and extraction method (Yip et al., 2024). Consequently, the biological effects of *Eucalyptus* preparations cannot be predicted solely from the amount of essential oil administered; characterization of their 1,8-cineole content and other major constituents is also important.

1,8-Cineole has attracted interest because of its reported antimicrobial, antioxidant, and anti-inflammatory properties. These activities provide plausible mechanisms for its application as a phytogenic feed additive, particularly under conditions involving intestinal dysbiosis, oxidative stress, or inflammation. Nevertheless, effects demonstrated using isolated 1,8-cineole should be distinguished from those produced by whole EEO because the latter contains numerous additional terpenoids that may exert additive, synergistic, or antagonistic effects.

9.2 Effects of 1,8-Cineole in Poultry

Evidence from poultry indicates that the response to 1,8-cineole depends on bird type, physiological condition, dose, and formulation. Cimrin (2019) evaluated dietary 1,8-cineole at 100 mg/kg in laying hens and found reduced feed consumption but also reduced egg production compared with some control treatments. Changes in selected egg-quality and blood parameters were also observed. These findings are important because they demonstrate that supplementation with an

isolated phytochemical compound does not necessarily improve all productive outcomes and that potentially beneficial biological activity must be considered alongside possible adverse effects on production. Di et al. (2022) demonstrated that dietary 1,8-cineole supplementation influenced growth performance, antioxidant capacity, immune function, and intestinal health in broiler chickens, with responses varying according to supplementation level.

Subsequently, Cimrin et al. (2020) investigated 100 mg/kg dietary 1,8-cineole in laying hens, focusing on egg-yolk fatty acid composition and lipid oxidation during storage. Supplementation altered the yolk fatty acid profile and affected storage-associated lipid peroxidation. These results indicate that dietary 1,8-cineole may influence lipid metabolism and oxidative stability of poultry products, although the practical importance of these changes requires consideration alongside its effects on laying performance.

The current manuscript also discusses Al-Musawi et al. (2020), who investigated 1,8-cineole in laying hens subjected to polychlorinated biphenyl-associated toxicity. The reported improvement in antioxidant-related responses supports a potential protective role of 1,8-cineole under experimentally induced oxidative challenge. However, this represents a specific toxicological model, and the findings should not be directly extrapolated to healthy commercial laying hens without further evidence.

Collectively, these studies demonstrate an important feature of the 1,8-cineole literature: its biological effects are context dependent. Improvements in antioxidant or physiological biomarkers should not automatically be interpreted as improvements in poultry productivity. Dose–response relationships therefore require considerably greater attention before an optimal dietary inclusion level can be proposed.

9.3 Microencapsulation and Improved Delivery of 1,8-Cineole

One limitation to the practical application of 1,8-cineole is its volatile and hydrophobic nature, which can affect stability, handling, gastrointestinal delivery, and biological availability. Encapsulation represents a promising strategy for protecting volatile phytochemical compounds and controlling their release within the gastrointestinal tract.

Strong poultry-specific evidence is provided by Jiang et al. (2021), who prepared 1,8-cineole microcapsules and evaluated them as feed supplements in broilers subjected to heat stress. Microencapsulation improved important pharmacokinetic characteristics of 1,8-cineole: the encapsulated preparation showed greater time to maximum plasma concentration, terminal half-life, and systemic exposure than non-encapsulated 1,8-cineole, while maximum plasma concentration was similar.

In heat-stressed broilers, dietary supplementation with 1% or 3% 1,8-cineole microcapsules was associated with improved body-weight gain, reduced intestinal inflammation, preservation of upper-ileal structure, and changes in intestinal microbiota. Jiang et al. (2021) also reported increased relative abundance of *Lactobacillus* and decreased *Salmonella* under the principal heat-stress comparison, while *in vitro* experiments demonstrated inhibitory activity against *Salmonella*. These findings provide evidence that improved delivery of 1,8-cineole may enhance its biological effectiveness and that its benefits under heat stress may involve interactions among intestinal microbiota, mucosal integrity, and inflammatory signalling.

However, these findings should not be interpreted as evidence that microencapsulated 1,8-cineole is universally effective at the same supplementation levels. The study was conducted under a defined heat-stress model, and the microcapsule itself contained a specific amount of entrapped 1,8-cineole. Therefore, percentages of the microencapsulated preparation should not be directly equated with the same percentages of pure 1,8-cineole.

9.4 Dose-Dependent Effects and Potential Limitations

The available evidence also highlights the need to consider possible adverse or neutral responses. Cimrin (2019) demonstrated that dietary 1,8-cineole at 100 mg/kg did not improve laying performance consistently and was associated with lower egg production compared with control treatments. Such findings are particularly important for a balanced review because phytochemical compounds should not be assumed to be beneficial merely because they are naturally derived.

10. Safety, Dose-Dependent Effects, and Limitations

Despite the potential benefits of *Eucalyptus*-derived phytochemical additives, their application in poultry nutrition requires careful consideration of dose, chemical composition, formulation, and duration of supplementation. Plant-derived products should not automatically be considered safe or beneficial at all inclusion levels. The biological response to phytochemical compounds is frequently dose dependent, and concentrations that produce favourable antimicrobial, antioxidant, or immunomodulatory effects may differ from those required to improve productive performance (Wang et al., 2024; Biswas et al., 2024).

10.1 Tannins and Other Non-volatile Constituents

An important distinction should be made between *Eucalyptus* leaf powder (ELP) and *Eucalyptus* essential oil (EEO). *Eucalyptus* leaves contain tannins and other non-volatile phytochemicals, whereas the essential oil consists predominantly

of volatile constituents such as 1,8-cineole and other terpenoids. Therefore, concerns regarding dietary tannins are particularly relevant to leaf-based preparations and extracts containing these compounds, and should not automatically be attributed to purified EEO.

The original literature cited in this manuscript confirms the occurrence of tannins in *Eucalyptus* foliage (Moore et al., 2005). Traditionally, high dietary concentrations of tannins have been regarded as antinutritional because tannins can interact with proteins and minerals and may interfere with digestive enzyme activity and nutrient utilization (Hidayat et al., 2021). Consequently, excessive inclusion of tannin-rich *Eucalyptus* leaf material could potentially reduce nutrient availability and compromise feed intake or growth.

However, describing tannins solely as detrimental would be an oversimplification. The physiological effects of tannins depend on their chemical structure, concentration, dietary context, and animal species. At appropriate concentrations, some tannin-containing phytochemical materials may exhibit antimicrobial, antioxidant, and anti-inflammatory activities (Choi & Kim, 2020). Thus, the presence of tannins should be regarded as an important dose- and preparation-dependent consideration, rather than evidence that *Eucalyptus* supplementation is inherently detrimental.

This distinction may partly explain differences between studies using ELP and EEO. Farhadi et al. (2017) reported that supplementation with *E. globulus* leaf powder at 1,000 or 3,000 mg/kg adversely affected growth performance during part of the experimental period, whereas the essential-oil treatments did not produce the same response. The authors suggested that antinutritional compounds present in the leaves, including tannins, could have contributed to the reduced performance. At the same time, both leaf powder and essential oil influenced immune responses, demonstrating that physiological and productive outcomes do not necessarily respond in parallel.

10.2 Dose-Dependent Responses to Eucalyptus Essential Oil

Dose is also important when EEO itself is administered. Mohebodini et al. (2021) evaluated *E. globulus* essential oil at 250–1,000 mg/kg diet and demonstrated that responses in growth performance, nutrient digestibility, antioxidant status, and cecal microbiota varied according to supplementation level. These findings indicate that increasing the amount of EEO does not necessarily produce a proportionally greater biological response. Establishing an optimal dietary concentration therefore requires dose–response evaluation rather than assuming that higher supplementation is more effective.

Variation in EEO composition further complicates determination of an optimal dose. As discussed previously, the proportion of 1,8-cineole and other terpenoids can vary considerably among *Eucalyptus* species, geographical origins, and extraction conditions (Yip et al., 2024). Consequently, two studies administering the same quantity of “eucalyptus essential oil” may expose birds to substantially different concentrations of individual bioactive compounds. Reporting only the amount of EEO without its chemical characterization limits reproducibility and makes direct comparison among feeding trials difficult.

10.3 Potential Limitations of 1,8-Cineole

Similar caution is required for purified 1,8-cineole. Although several studies demonstrate antioxidant, anti-inflammatory, intestinal, and stress-related benefits, productive responses are not universally favourable. Cimrin (2019) reported that dietary 1,8-cineole at 100 mg/kg in laying hens was associated with reduced egg production compared with the control treatment, despite changes in other physiological and egg-quality parameters. This finding illustrates that improvements in selected biomarkers should not automatically be interpreted as improvements in overall productive performance.

Formulation also influences biological activity. Jiang et al. (2021) demonstrated that microencapsulation altered the pharmacokinetic behaviour and biological effectiveness of 1,8-cineole in broilers. Consequently, results obtained using encapsulated 1,8-cineole cannot be directly extrapolated to equivalent nominal concentrations of the unencapsulated compound. Delivery technology should therefore be considered alongside dietary concentration when comparing experimental outcomes.

10.4 Current Evidence Gaps and Practical Limitations

Several limitations currently prevent definitive recommendations regarding *Eucalyptus* supplementation in commercial poultry production. First, relatively few controlled poultry studies have investigated chemically characterized EEO or purified 1,8-cineole. Second, substantial heterogeneity exists in *Eucalyptus* species, plant material, extraction methods, supplementation levels, delivery systems, experimental duration, bird age, basal diet, and environmental conditions. Third, some studies have used mixtures containing *Eucalyptus* together with other essential oils, probiotics, or phytochemical compounds, making it impossible to attribute the observed effects specifically to *Eucalyptus*.

Long-term safety and practical applicability also require further investigation. Most available studies have been conducted over relatively short experimental periods, whereas information regarding prolonged supplementation, tissue residues, interactions with other feed additives, product sensory characteristics, and economic feasibility remains comparatively limited. Furthermore, evidence obtained under controlled experimental challenges may not necessarily predict responses under commercial production conditions.

Conclusion

Eucalyptus essential oil (EEO) and its major bioactive constituent, 1,8-cineole, show promising potential as phytogetic feed additives in poultry. Available evidence suggests beneficial effects on growth performance, gut health, antioxidant status, immune responses, and resilience to environmental and disease-related challenges. However, responses vary according to *Eucalyptus* species, chemical composition, dose, formulation, and production conditions. Potential limitations, including tannins in leaf-based preparations and dose-dependent adverse responses, should also be considered. Future studies should focus on standardized and chemically characterized EEO, optimal supplementation levels, advanced delivery systems such as microencapsulation, long-term safety, and validation under commercial conditions. Overall, EEO and 1,8-cineole represent promising natural tools for supporting sustainable poultry production, although further evidence is required before definitive feeding recommendations can be established.

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